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No. 1. INDUCED RADIOACTIVITY EXCITED IN AIR AT THE FOOT OF WATERFALLS,
BY J. C. McLENNAN.
No. 2. SOME EXPERIMENTS ON THE ELECTRICAL CONDUCTIVITY OF ATMOSPHERIC AIR,
BY J. C. McLENNAN AND E. F. BURTON.

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INDUCED RADIOACTIVITY EXCITED IN AIR AT THE FOOT OF WATERFALLS

BY

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INDUCED RADIOACTIVITY EXCITED IN AIR AT THE FOOT OF WATERFALLS*

I. *Introduction.* The fine drops of spray into which water is broken on passing over waterfalls were found by Lenard[1] to communicate, on striking the wet rocks at the foot of a fall, a negative charge of electricity to the surrounding air and a positive charge to the water. From a number of laboratory experiments with jets impinging on metal plates he obtained the same results with pure water, but found that the presence of any impurity greatly lessened the effect. With certain solutions—notably sodium chloride in water—the action weakened with an increase in the strength of the solution, and was finally reversed, a positive charge being communicated to the air and a negative charge to the liquid. The splashing of rain he found imparted a negative electrification to the surrounding air, while the breaking of waves on the sea shore electrified it positively. The experiments of J. J. Thomson[2] and of Elster and Geitel[3] have confirmed these observations, and, while shewing that the sign and the amount of the electrification imparted varied both with the liquid and with the gas in which the splashing occurred, yet the splashing of pure water in air always gave a negative electrification.

A little over a year ago Elster and Geitel[4] found that if a negatively electrified wire were exposed for some hours in the open air or in a very large room, it became temporarily radioactive. Since then a number of observations have been made upon this effect, and the consensus of opinion appears to be that it is due to the presence in the atmosphere of some peculiar constituent similar to the emanation from thorium, which has been shewn by Rutherford[5] to induce radioactivity in any body with which it comes in contact, especially when that body is negatively electrified.

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* Read before the American Physical Society, at Washington, Dec. 31st, 1902.

[1] Wied. Ann., Bd. 46, p. 584, (1892).

[2] J. J. Thomson, *Discharge of electricity through gases*, p. 17.

[3] Wied. Ann., Bd. 47, p. 496, (1892).

[4] Phys. Zeit., No. 40, p. 590, (1901).

[5] Phil. Mag., No. 49, pp. 1 and 161, (1900).

The difficulty of determining and of regulating the atmospheric conditions for observations upon this excited or induced radioactivity suggested the desirability of resorting, for purposes of experiment, to a locality where exceptional electrical conditions were known to exist permanently in the atmosphere. Niagara Falls, according to Lenard's results, is preeminently such a locality, and, through the kindness of the Hon. Thomas Walsh, Superintendent of the Niagara Falls National Park Reservation, the author was enabled in September last to carry out a short series of observations upon excited radioactivity at the foot of the waterfall. The general result of the investigation was that during the course of the experiments the amount of radioactivity induced in a wire exposed at the foot of the waterfall was found to be very much less than that in a wire exposed in the same manner in Toronto.

II. *Apparatus.* In these observations the measurements were made with a quadrant electrometer of the Mascart type as constructed by Carpentier. The silk suspension in the original apparatus was replaced by a phosphor bronze strip less than 0.025 millimetres in thickness, which was attached at its upper end to an ebonite rod to secure insulation. The needle was kept charged by a battery of small storage cells similar to those installed in the Reichsanstalt and the deflections were measured by the movement of the image of an incandescent lamp filament upon a transparent scale placed at a distance of one metre from the electrometer.

With a potential of 480 volts applied to the needle, the sensibility of the instrument was such as to produce a deflection of 1000 mms. on the scale for a potential difference of one volt between the quadrants. In measuring the induced radioactivity, bare copper wire no. 24 was exposed in the open air by means of specially constructed insulating supports (Fig. I), attached to a series of bamboo poles erected at convenient distances. The wire was charged by a small Toepler Holtz electrical machine driven by a water motor, which maintained a potential of from eight to ten thousand volts.

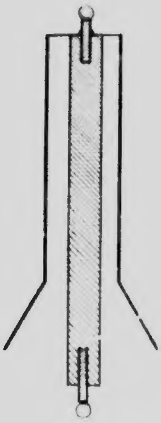

Fig. 1

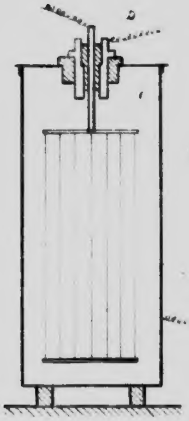

Fig. 2

The insulator shewn in Fig I consisted of a brass tube about 20 centimetres long, closed at one end and having a bell-shaped opening at the other. Into this tube an ebonite rod was screwed which could be easily removed when it was necessary to renew its surface. Hooks fastened to the tube and to the ebonite rod provided for the support of the insulator and the suspension of the wire. In the experiments at the foot of the waterfall it was found that, with these insulators, a wire could easily be maintained at a potential of 10,000 volts for hours, even in a drenching spray.

The exposed wire was tested for induced radioactivity by means of the apparatus shewn in Fig. II. *A* was a galvanized iron cylinder about 30 cms. high and 20 cms. in diameter, resting on an insulated platform and having a movable cover provided with a flanged opening into which was fitted an ebonite plug about five centimetres in diameter. A brass tube *C* was passed through this plug and into it a second ebonite plug was tightly fitted. This second plug carried a brass rod *D* from which *B*, a brass reel, was suspended, and on this reel the wire to be tested was wound. The brass tube *C* which was earthed throughout the measurements served as a guard ring and prevented any leak from the vessel *A* to the rod *D* across the ebonite plugs.

The saturation current due to spontaneous ionization of the air in the vessel having been first determined by connecting the supporting rod *D* to the electrometer in the usual way and applying a potential of 100 volts to *A*, the exposed wire was then wound on the reel, inserted in the vessel, and the saturation current again ascertained. Any increase observed in the ionization current was taken as a measure of the radioactivity induced in the exposed wire.

As it was impossible, in setting up the apparatus, in two different localities, to be certain that it was of exactly the same sensibility, a standard of ionization was deemed necessary for purposes of comparison. A radioactive substance which the writer had in his laboratory at the time of making the experiments was chosen, and a small quantity in a glass phial being found to give a constant ionization current when placed in a given position in the chamber A, this current was adopted as a standard and the ionization currents measured in the various tests were expressed in terms of it.

III. *Experiments.* Both before proceeding to Niagara and after returning, a series of exposures was made in the quadrangle of the University at Toronto. Copper wires, approximately 30 metres long, were exposed for periods of two hours at a potential of 8,000 to 10,000 volts on a number of days. After a wire had been exposed it was placed in the ionization chamber, the saturation current measured and its radioactivity, thus ascertained, was expressed in terms of the standard radioactive substance. The resulting values, taking the standard saturation current as unity, showed considerable variation in the amount of radioactivity excited, the highest value observed being 1.75 and the lowest 0.6. The intermediate values ranged between these limits but were quite irregular and seemed to depend more upon the existence of wind and its velocity than other changes in the weather. The occurrence of showers did not exert a noticeable effect on the amount of radioactivity excited. It was frequently observed that exposures made in the morning gave greater induced radioactivity than those in the afternoon, but that exposures made after sunset gave values generally equal to and sometimes greater than those of the morning.

The following numbers which represent the observations made upon one day are typical and shew this variation:

Exposure	Excited radioactivity
9 A.M.—11 A.M.	.8
1 P.M.—3 P.M.	.6
6 P.M.—8 P.M.	1.0
9 P.M.—11 P.M.	1.1

The observations were made in Toronto between September 5th and 12th, and between the 19th and 23rd, those made at Niagara occupying the interval. The values in the two series at Toronto exhibited similar variations and were confined in both cases within the limits mentioned. The weather throughout, except for a few showers, was uniformly fine.

In conducting the experiments at Niagara Falls the electrometer and its attachments were set up in the basement of the landing-station at the foot of the inclined railway. It was a large room having stone walls and a cement floor, and, being fairly dry, was well suited for making the tests. The electrical machine which was intended for charging the wire was also located in this room, and the wire to be exposed was led from it out of a window and suspended in three stretches of about 30 metres each, the insulation being secured as already described. The situation was admirably adapted for making exposures, as the wire could be led within a metre or two of the vast mass of falling water. The first length of wire was generally enveloped in a very fine spray, that which surrounded the second was heavier, while the down-pour upon the third resembled the heaviest rain. A point of peculiar interest in connection with the first exposure was that the wire upon suspension in the spray immediately became negatively charged to a potential of about 7,500 volts. This voltage was maintained with but little variation, both day and night, during the period covered by the experiments and the sign of the electrification was invariably negative.

The results of a number of tests with the different sections of the wire showed that the removal of the third generally caused a drop in the potential of the remaining sections from 7,500 volts to about 5,500 volts, while the first section, when exposed alone, gave a potential varying from 3,000 to 4,000 volts. From this it was evident that the spray was a cause of the electrification and that the potential of the wire was largely determined by its density. On account of the permanency of this electrification of the exposed wire, the electrical machine necessary in the Toronto experiments was not employed.

In testing for induced radioactivity, the wire was exposed for periods of about two hours and was removed in sections, each section being replaced by a new length. The same method of testing was used as in Toronto and the results expressed in terms of the standard radioactive substance. Exposures were made on four different days with the following results, A, B, and C denoting the sections of the wire, of which A was that nearest the observing station and C that nearest the waterfall.

Date.	Section of wire tested	Induced radioactivity. Saturation current of standard substance=1.
Sept. 12th.	A.	0.1
	B.	0.31
	C.	None observed.
Sept. 13th.	A.	0.16
	B.	None observed.
	C.	Not exposed.
Sept. 16th.	A.	0.13
	B.	0.14
	C.	0.11
Sept. 17th.	A.	0.15
	B.	0.12
	C.	None observed.

From these numbers it will be seen that but little variation was observed in the radioactivity excited in the sections A and B. In C however, which was nearest the waterfall, measurable radioactivity was present in only one of three exposures. Ordinarily this section was drenched by masses of falling water in addition to being surrounded by fine spray such as enveloped the rest of the wire. But on Sept. 16th the air currents during exposure were such as to drive aside the sheets of water and permit only the fine spray to come in contact with the section. As already stated, the spray enveloping the section B was generally heavier than that in contact with A, but the condition was not permanent, as the spray was blown about by gusts of wind whose direction was continually changing in the gorge.

The chief interest attaching to the results was that the radioactivity excited was much less than that in Toronto. It will be noticed that the greatest amount of radioactivity observed at Niagara Falls was 0.3 while the least observed in Toronto during the period covered by the experiments was 0.6. The numbers also show that on the average the radioactivity excited at Toronto was at least from five to six times greater than that induced at the Falls. The observations were not made in the two places at the same time and a direct comparison is therefore impossible, but as there was no break in the weather during the progress of the experiments and as the values found in Toronto before going to the Falls were almost the same as those obtained on returning, one is warranted in concluding that the air at the foot of the waterfall permanently possesses less power to excite radioactivity than the air of localities at some distance. While the experiments were in progress the spray was frequently examined for radioactivity. This was done by collecting a quantity, evaporating it and testing the containing vessel. In no case was any trace of radioactivity observed.

Assuming then that excited radioactivity is caused by the presence in the atmosphere of some peculiar constituent, the experiments which have been described would seem to shew that this constituent is present to a much less degree in the atmosphere in the neighbourhood of waterfalls than in places remote from them. That it is possible to reduce the amount of this constituent present in the atmosphere is shewn by some experiments recently performed in the Physical Laboratory of the University of Toronto. The windows and doors of a large room which had been well aired were closed and, while of course they were not made air-tight, it may be assumed, as they were close fitting, that the quantity of outside air which they admitted was relatively small. An electrical machine at one end of the room was set in action and a number of zinc discs attached to a wire leading from its negative terminal were suspended for an hour simultaneously at different points in the room. Upon testing these discs for radioactivity by the method employed by C. T .R. Wilson,[1] it was found that the radioactivity excited in the discs regularly increased with the distance from the machine.

It was also found, when a series of discs were consecutively exposed for an hour in a fixed position in the room after it had been well aired and closed, that the radioactivity excited regularly diminished with the time. The admission of a considerable volume of fresh air, as by the opening of a window, immediately caused an increase in the amount of radioactivity excited in the exposed discs. It was evident, therefore, that the electrical machine in action served as a means of removing from the atmosphere surrounding it the constituent upon whose presence the excited radioactivity depended.

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[1] Proc. Roy. Soc., Vol. 68, p. 151, (1901).

In seeking for an explanation of the diminished radioactivity excited at the Falls, the experiments just described suggest the presence of an agency having an effect similar to that of the electrical machine on the air in the room. The negative electrification of the wire when in the spray area pointed to the presence of this agency in the spray itself. The time at the writer's disposal did not permit of a direct investigation into the charge carried by the spray, but the negative electrification of the wire, which it will be remembered was always present, would seem to indicate a similiar electrification of the spray.

That this was the case may be deduced from the results of some recent experiments by Schmauss[1], who found that water became negatively electrified when dropped through air traversed by Röntgen rays. He explained his results by a reference to the experiments of Rutherford[2],and of Zeleny[3],in which it was shown that a stream of air, when ionized by Röntgen rays and directed against an insulated conductor, imparted to it a negative charge owing to the greater velocity of diffusion of the negative ions. These experiments, in which the gas was in motion and the insulated conductor at rest, Schmauss considered the converse of his own.

Now in the experiments we are considering we have spray moving through air which from Lenard's observations contained a considerable excess of negative ions. The moving spray, according to Schmauss's results would acquire a negative charge from the air present and would then be in a condition to attract to itself the radioactive emanation and on falling would carry it down to the river below. This process would result in a diminution in the amount of the emanation present in the air at the foot of the waterfall and would therefore account for the small amount of induced radioactivity observed in that locality. This explanation requires the spray itself to be radioactive, but when the enormous volume of the spray and the very limited amount of induced radioactivity observed in the locality are taken into account, together with the known decay of induced radioactivity, it would appear reasonable to conclude that experiments conducted with very much larger quantities of spray than those in the writer's tests would be necessary to obtain observable results.

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[1] Wied. Ann. Bd. 9, pp. 224-237 (1902).

[2] Phil. Mag., Vol. 43, p. 241 (1897).

[3] *Ibid.*, Vol. 46, p. 120 (1898).

The foregoing would also serve to explain the negative electrification of the suspended wire. From the observations of Lenard we should expect a positive charge to be developed on the wire by the splashing of the spray. Schmauss has shown, however, that the negative charge gained by drops of water in falling through ionized air may be so great as to overcome the Lenard effect, and since the air enveloping the spray at the fall was not only ionized but also contained an excess of negative ions it is evident that all the conditions were present for producing a negative electrification of the suspended wire. It is probable, too, that a considerable portion of the negative charge developed on the wire was taken up directly from the negatively charged air which was constantly in motion about it.

IV. *Radioactive Rain and Snow.* In order to ascertain, if possible, the effect of variations in the weather upon the radioactive state of the atmosphere, the writer made a series of daily observations in the month of November. During this period both rain and snow storms occurred. The falling of rain was not found to produce any marked change in the radioactive power of the atmosphere, although, as already shewn by C. T. R. Wilson[1], the rain itself when tested was active. The falling of snow, however, was accompanied by a very considerable drop in the value of the excited radioactivity. For example, on November 25th the air was dry and cold and the morning exposure gave a value of 0.92, that for the afternoon exposure being 0.66. The next morning snow began to fall heavily and an exposure was made in it for two hours. The resulting value for the excited radioactivity was 0.3. The snowfall continued throughout the day and the value for the afternoon exposure was again 0.3. This storm was general throughout Ontario and the snow, which fell to a depth of about three inches, remained for some days on the ground and did not entirely disappear until November 30th. Tests made for excited radioactivity in the interval shewed values ranging from 0.2 to 0.4. On December 1st an exposure made about noon gave a value of 0.9. On this day the weather was again mild and the snow had disappeared. Exposures made in the mornings of December 2nd, 3rd, 4th, and 5th gave the values, 0.8, 1.1., 0.9, 0.9, respectively. The weather continued mild until December 5th, when the temperature dropped below 0°C. On December 6th the cold weather still prevailed and an exposure made from 1 to 3 o'clock in the afternoon gave a value of 0.92. Shortly after 3 o'clock a light fall of fine snow began, which continued throughout the night. An exposure was made from 3.30 to 5.30 p.m. and also one from 9 to 11 p.m. The resulting value for the former was 0.2 and for the latter 0.32. As the numbers just given indicate, the falling of snow on both occasions was accompanied by an immediate drop in the excited radioactivity. It will also be noticed that while the ground was covered with snow from the first fall the diminished activity continued. The snow on both occasions was collected as it fell, melted and evaporated, and the residue found to be highly radioactive. Snow which fell in the first storm was tested after it had lain two days on the ground and was found still to possess about one per cent. of its original activity.

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[1] Proc. Camb. Phil. Soc., Vol. xi., Pt. vi., p. 428.

These results, it will be seen, lend support to the theory that the constituent of the atmosphere to which the excitation of radioactivity is due is an emanation from the earth's surface. It would also seem from the values found for the induced radioactivity that this emanation is cut off to a considerable extent when a wide area of the earth's surface is thickly covered with snow.

The limited number of observations made hardly justifies a definite conclusion as to the manner in which rain and snow becomes radioactive; but it is possible that water vapour in moving through the air, whether in the form of clouds or otherwise, gains a negative charge, in the same manner as the spray at Niagara Falls, attracts to itself the emanation in the air, and consequently becomes radioactive. This view is supported by the results of some experiments recently made by the writer. Water vapour was condensed from the atmosphere upon the surface of a number of cylinders containing a freezing mixture of ice and salt. The water thus obtained was evaporated in a metallic tray and the residue tested for radioactivity. Such tests were made daily for a period of two weeks. In most of them no radioactivity was observed, but slight traces were noticeable in several, and on four occasions the radioactivity excited was very marked. The experiments were all conducted with equal care and no cause was apparent for the different results of the observations.

The thanks of the writer are due to Mr. J. S. Plaskett, B.A., for assistance in conducting the experiments which at Niagara were attended with considerable difficulty, and to Mr. J. C. Rothery, Superintendent of the Niagara Falls' Park and River Railway for facilities afforded in transporting the apparatus.

SOME EXPERIMENTS ON THE ELECTRICAL CONDUCTIVITY OF ATMOSPHERIC AIR

BY

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SOME EXPERIMENTS ON THE ELECTRICAL CONDUCTIVITY OF ATMOSPHERIC AIR.*

I. *Introduction.* In a paper by H. Geitel[1] reference is made to a gradual increase observed in the conductivity of a mass of atmospheric air after being confined in an air-tight chamber. This effect was found to require from four to five days to reach its maximum value and was observed in localities where no thorium compound or other known radioactive substances existed. In a subsequent investigation Elster and Geitel[2] found that air which had been confined for some time in closed caves or house-cellars possessed an abnormally high conductivity. This phenomenon, together with the observed increase in conductivity mentioned above, they concluded, could not be due to the presence of dust or water vapour. They traced it rather, in both cases, to the existence of some undetermined radioactivity in the confining walls. More recently these physicists[3] discovered that atmospheric air possessed the property of exciting induced radioactivity in bodies exposed under negative electrification. This phenomenon of induced or excited radioactivity had been previously observed by Rutherford[4] in bodies exposed to air drawn from the neighbourhood of thorium compounds and had been connected by him very directly with an emanation which these salts emit. This emanation he found possessed the property not only of exciting radioactivity in all solid substances in its neighbourhood, but also of ionizing any gas with which it was in contact.

Since atmospheric air has been shewn by Elster and Geitel,[5] C. T. R. Wilson[6] and others to be continually ionized by some agent, and since it has also been shewn to possess the property of exciting radioactivity one is forced to conclude that there is present in the air an emanation possessing properties similar to that emitted by thorium compounds. Hitherto the source of such an emanation has not been determined, but, as the phenomena of induced radioactivity and spontaneous ionization universally characterize atmospheric air, it seems evident, since thorium compounds are but sparsely distributed in nature, that sources other than these must exist.

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*Read before the American Physical Society at Washington, Dec. 31st, 1902.

[1] Phys. Zeit., ii, pp. 116-119, (1900).

[2] Phys. Zeit., ii, pp. 560-563, (1901).

[3] Phys. Zeit., ii, p. 590, (1901).

[4] Phil. Mag., No. 49, pp. 1 and 161, (1900).

[5] *Loc. cit.*

[6] Proc. Roy. Soc., vol. 69, pp. 277-282, (1901).

Recalling the experiments of Elster and Geitel, it seems probable that the earth's surface, and possibly too the material used in the construction of their apparatus, are sources of this emanation. As but little evidence existed in favour of this conclusion, the writers recently made a series of observations upon atmospheric air confined in air-tight vessels of different metals. The result of the investigation showed that the conductivity of the enclosed air depended very largely upon the material of which the receiver was made, and the effects observed would seem to indicate that all metals in varying degree are the sources of a marked though feeble radioactive emanation.

II. *Apparatus.* In these observations the air whose conductivity was to be measured was confined in a cylinder 125 cms. in length and 25 cms. in diameter, similar to that shown in Fig. I. In the first experiments it was made of sheet iron coated with zinc, and in the later experiments linings of various metals were inserted in order to examine their effect upon the conductivity of the enclosed air. The bottom and cover were removable, and, when in position, were made air-tight by means of cement. Into a flanged opening in the cover was fitted an ebonite plug about 5 cms. in diameter. A brass tube *B* was passed through this and into it a second ebonite plug was tightly fitted. This second plug carried a brass rod *C* which extended almost to the bottom of the cylinder. The brass tube *B*, which was earthed throughout the measurements, served as a guard ring and prevented any leak from the vessel to the rod *C* across the ebonite plugs. The conductivity was measured by placing the cylinder upon an insulated platform, charging it by means of a set of small storage cells to a potential of 165 volts, which sufficed for the saturation current, and observing the rise in potential of the electrode *D* which was joined to a quadrant electrometer in the usual manner. The sensibility of the elec-

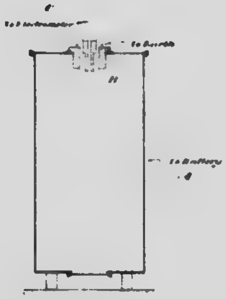
C
To Electrometer
To Earth
B
To Battery
A

Fig. 1

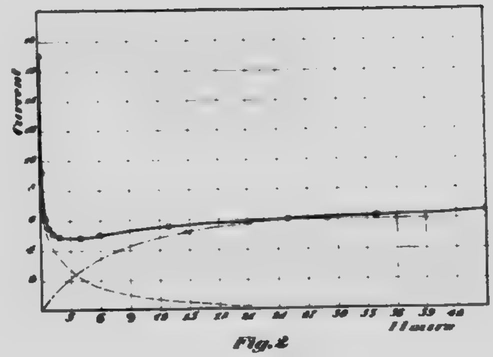
Current
3
6
9
12
15
18
21
24
27
30
33
36
39
42
Hours

Fig. 2

trometer was such as to produce a deflection of 1,000 mms. on the scale for a potential difference of one volt between the quadrants.

III. *Conductivity Measurements: Time Effect.* Before enclosing air for examination the cylinder was placed in an open window in the laboratory, with the ends removed, and the air allowed to blow through it for some time. The top and bottom were then replaced, cemented in position, and the cylinder connected with the electrometer as quickly as possible. Measurements on the conductivity were made at intervals of a few minutes at first, and it was invariably found that a rapid decrease in the ionization took place until a minimum value was reached. The conductivity then slowly increased and approached a limiting value in the course of two or three days.

TABLE I.—CURRENT: ARBITRARY SCALE.

Time.	Pressure—501.0 cms.	Pressure—74.2 cms.
10 mins.	30.0	17.1
15 "	....	9.3
30 "	17.5	6.2
50 "	13.2	5.5
1 hour	12.0	....
1.25 "	....	5.13
1.5 "	9.9	....
1.75 "	8.9	5.1
2.00 hours	8.0	4.9
4.00 "	6.6	4.8
5.00 "	7.6	....
6.00 "	....	5.0
10.00 "	....	5.8
22.00 "	19.2	....
25.00 "	....	6.0
29.00 "	....	6.0
32.00 "	22.0	....
34.00 "	....	6.3
44.00 "	24.0	....
45.00 "	....	6.5

In re[illegible] tests carried out in this manner with the zinc cylinder it [illegible] found that, while the initial conductivity varied from day to day, there was always observed a rapid decrease to a constant minimum followed by a gradual rise to a constant limiting value. A typical set of values for the conductivity of air confined in the zinc cylinder at atmospheric pressure is given in the third column of Table I, the currents being expressed in arbitrary units, and the times being taken from the closing of the cylinder. The ionization curve for these values (Fig. II) shows that the minimum current, 4.8, was reached in about four hours after the air was enclosed. After about eighteen hours the curve indicates that the conductivity was tending towards a limiting value, which the reading taken after forty-four hours showed to be about 6.5.

As a variation in the experiments a series of tests was made with air confined in a receiver at high pressures. The cylinder in this case was of heavy rolled iron coated with zinc and was of the same dimensions as that formerly used. The results of observations on the conductivity of air confined at a pressure of about seven atmospheres are given in the second column of Table I, the scale used being the same as before. The curve representing these values is shewn in Fig. III, and exhibits the same characteristics as that for the lower pressure. We have again the rapid decrease to a minimum followed by a gradual rise tending towards a limiting value. The minimum conductivity in this case was about 6.6, and was reached in about four hours after the required pressure in the cylinder had been obtained. The time occupied in pumping the air was about one hour.

In seeking for an explanation of the curves shewn in Figs. II and III, their twofold origin, as indicated by the dotted lines, is at once suggested by the conductivity in the initial stage being due to an agent subject to rapid decay, and that in the second to one whose power shews a gradual increase. The first of these dotted curves is similar to that given by Rutherford[1] for the conductivity of the air in a chamber which has been cut off from a second containing thorium oxide after the two had been in communication for some time. The second dotted curve is similar to that given by him for the conductivity of the air in a chamber which had been placed in communication with one containing thorium oxide.

It will thus be seen that the first portion of the curves in Figs. II and III can be explained upon the supposition that a radioactive emanation, probably having its origin in the earth's

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[1] Phil. Mag., Jan., 1900, p. 6.

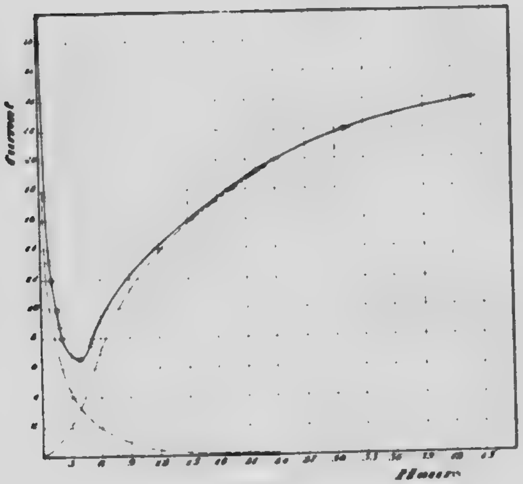
Current
3
6
9
12
15
18
21
24
27
30
33
36
39
42
45
Hours

Fig. 3

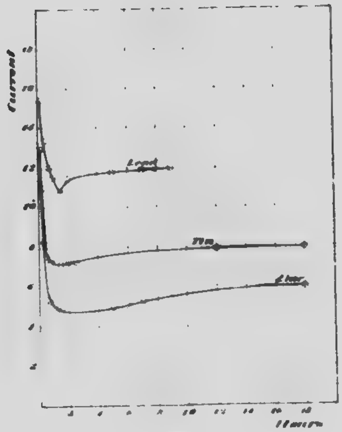
Current
Lead
Tin
Zinc
6
4
2
2
4
6
8
10
12
14
16
18
Hours

Fig. 4

surface, was introduced into the cylinder with the air, the decay in this emanation being the cause of the decrease in the conductivity, and the second portion upon the supposition that a radioactive emanation is given off by the walls of the containing vessel. On this view the limiting value to which the conductivity curves tend would represent a condition of equilibrium, where the rate of decay of the emanation is equal to the rate at which it is produced.

As both the low and the high pressure cylinders were made of the same material and were of the same size, one would expect the same amount of the emanation to be present in both when the steady state was reached. With an easily absorbed radiation from this emanation, we should obtain a limiting conductivity independent of the pressure. But, since a very great difference was found in the limiting conductivities at the two pressures, it would appear that the radiation possesses considerable power of penetration and is not easily absorbed.

The difference in the initial conductivities given in the second and third columns of Table I may also be readily explained by the difference in the air pressures. The time required to fill the high pressure cylinder and the decay taking place during that time in the emanation introduced with the air preclude a comparison of the amounts of active emanation present in each cylinder when the first observations upon their conductivities were made; but if the amount in the high pressure cylinder were equal to or greater than that in the low pressure cylinder, the difference in the initial conductivities is explained, while, if it were less, the greater density of the air in the high pressure cylinder and the consequent greater absorption would still account for the higher conductivity.

IV. *Effect of Different Metals.* To ascertain whether the conductivity of the air enclosed was affected by a change in the metal composing the walls of the receiver, linings of tin and lead were in turn fitted into the zinc cylinder used in the first experiment. Tests of the conductivity were made both with and without the tin and lead linings. Before each test the cylinder was well aired and sealed in the manner already described. As soon as the air was enclosed measurements on the conductivity were begun and continued at stated intervals as before.

TABLE II.

Time.	Current: Arbitrary Scale.		
	Zinc.	Tin.	Lead.
10 minutes	13.0	13.0	15.4
15 "	8.3	11.0	....
30 "	5.4	7.6	13.4
45 "	5.3	7.3	12.1
1.0 hours	5.0	....	11.55
1.5 "	4.85	7.2	10.8
2.0 "	....	7.3	11.5
2.5 "	....	7.3	....
5.0 "	5.0	....	11.8
7.0 "	5.3	....	11.9
9.0 "	....	....	12.0
12.0 "	....	7.9	....
18.0 "	6.0	8.0	....

The values obtained for the conductivity with each of the metals are given in Table II, and curves representing these values are shown in Fig. IV. The curves for the different metals, it will be seen, have the same characteristics. In each there is a rapid drop to a minimum and a gradual rise towards an ultimate limiting value. It is interesting to note that a considerable difference was found in the minimum conductivities for the three metals, and that the final limiting values also varied. The decay of an emanation introduced into the cylinders with the [illegible] would again account for the first portion of the curves, a radioactive emanation from the metallic walls would explain the existence of the second portion, while the differences in the minimum and limiting values may be considered to have their origin in variations in the rate at which the emanation is given off by the different metals. In this connection it will be noted that the limiting values of the conductivities range according to the atomic weights of the metals, lead having the highest, tin the next and zinc the lowest.

V. *Effect of Variations in Pressure.* In order to investigate the relation between the conductivity of air and the pressure at which it was confined, the heavy cylinder was filled to a pressure of about seven atmospheres and allowed to stand for some

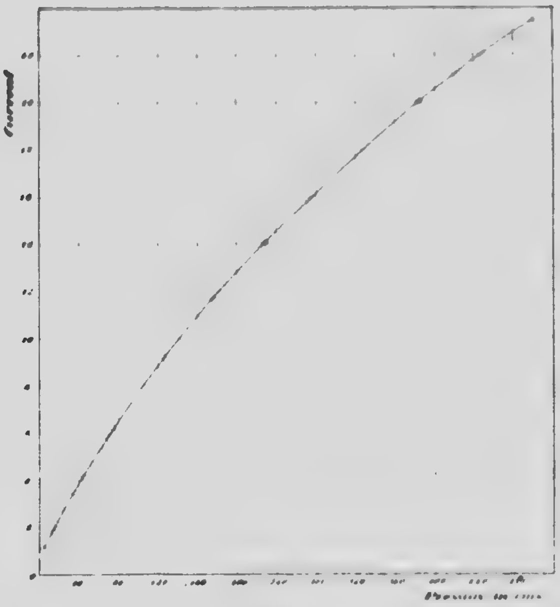

Fig. 5

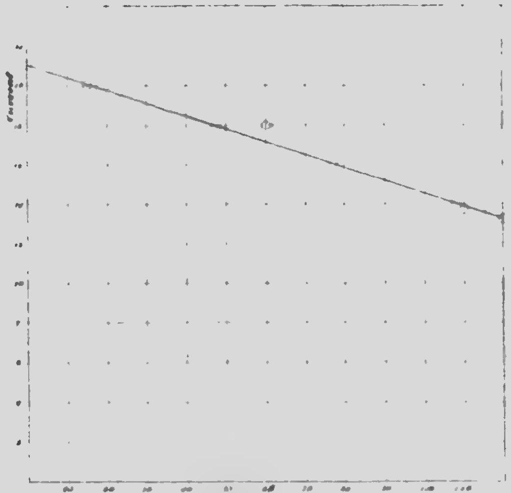

Fig. 6

days until its conductivity assumed a constant value. The air was then allowed to escape gradually, and the pressure reduced from 501.0 cms. to 4.4 cms. of mercury, the conductivity being measured at these and at various intermediate pressures. The results are given in Table III, and the conductivity curve in Fig. V.

TABLE III.

Pressure in Cms.	Current: Arbitrary Scale.
501.0	23.5
481.0	22.7
420.0	21.2
384.0	20.3
272.0	15.8
227.0	14.1
176.0	11.7
125.0	9.3
74.2	6.5
69.3	5.8
62.0	5.4
53.0	4.7
44.2	4.2
35.0	3.5
22.4	2.7
18.2	2.2
14.0	1.8
4.4	1.1

The ionization curve so nearly approaches a straight line that we may almost conclude, in view of the wide range of the pressures examined, that the conductivity was proportional to the pressure. This result is what we should expect to obtain with an emanation maintained at a constant strength and emitting a radiation of a penetrating nature.

VI. *Penetrating Rays from External Sources.* While the effects described up to the present may be explained by supposing the ionization to be caused by a radioactive emanation sent off from the metals, it has been found that part of the conductivity cannot be accounted for in this way, but must be attributed to an active agent external to the receiver.

The heavy cylinder referred to above was filled with air to a pressure of about 400 cms. of mercury and allowed to stand until its conductivity had become steady. It was then placed in an insulated galvanized iron tank, 1.5 metres in height and .75 metres in diameter, which was gradually filled with water so as to surround the cylinder with a layer 25 cms. in thickness. The initial conductivity before the water was admitted was 21.1. As the current rose the conductivity decreased and fell to 13.3 when the tank had been filled. The values for the conductivity during the experiment are given in Table IV and are represented by the curve shewn in Fig. VI. From these values it will be seen that the loss was almost directly proportional to the rise of the water, and that the total fall in conductivity was about 37 per cent.

TABLE IV.

Depth in Cms.	Current : Arbitrary Scale.
0.0	21.1
15.0	20.5
60.0	18.0
77.0	17.0
97.0	14.3
110.0	13.75
120.0	13.3

The experiment was repeated with the cylinder placed in a tank 50 cms. in diameter. This tank permitted the cylinder to be surrounded by a layer of water 12.5 cms. in thickness, and it was found when the water was poured in that the conductivity fell off 17.5 per cent.

From these results it is evident that the ordinary air of a room is traversed by an exceedingly penetrating radiation, such as that which Rutherford has shewn to be emitted by thorium, radium and the excited radioactivity produced by thorium and radium.

In order to reach definite conclusions regarding the extent and true character of the effect of various metals upon the conductivity of the air which they enclose it would be necessary to entirely cut off the enclosing vessel from the action of any external radiation and the writers have not yet carried their experiments to this point.

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